ZooKeys 1203: 197–210 (2024)
DOI: 10.3897/zookeys.1203.118978

Research Article

Current and future potential distribution of two bamboo pests in China: *Anaka burmensis* and *Cicadella viridis* (Hemiptera, Cicadellidae)

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Abstract

China's bamboo output is closely associated with its national economy; however, it is currently rapidly declining due to damage from the pests *Anaka burmensis* and *Cicadella viridis*. Identifying regions that are environmentally suitable for these pests is a critical step in their effective control. Therefore, in this study, we used a Maxent model to predict their current and future potential areas of distribution (2021–2040, 2041–2060, and 2061–2080) and explored changes over time using distribution data and related environmental variables. The model results demonstrates that the current potential areas of distribution of *A. burmensis* are predominantly concentrated in several provinces of southern and central China, such as Guizhou, Guangxi, and Hubei, whereas the current potential areas of distribution of *C. viridis* are primarily in many provinces across southern, central, and northeastern China. In the future, the potential distribution of *A. burmensis* will increase and move minimally, whereas the potential distribution of *C. viridis* will decrease and move considerably. The results of the present study provide vital information for predicting the spread and outbreaks of *C. viridis* and *A. burmensis* and provide a reference framework for developing management strategies to control these two pests, thereby minimizing economic loss in the bamboo industry.

Key words: Climate change, distribution areas, Maxent model

OPEN ACCESS

Academic editor:
J. Adilson Pinedo-Escatel
Received: 18 January 2024
Accepted: 7 May 2024
Published: 30 May 2024

ZooBank: https://zoobank.org/094DD97D-26DA-4AD3-BBD5-958331BE2148

Citation: Zhao Z, Yang L, Chen X (2024) Current and future potential distribution of two bamboo pests in China: *Anaka burmensis* and *Cicadella viridis* (Hemiptera, Cicadellidae). ZooKeys 1203: 197–210. https://doi.org/10.3897/zookeys.1203.118978

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Introduction

Bamboo comprises all members of the subfamily Bambusoideae and is the only lineage in the Poaceae family that has adapted and diversified to forest habitats (Judziewicz et al. 1999; Grass Phylogeny Working Group 2001; Bamboo Phylogeny Group 2012). Bamboo plants are mainly distributed in the tropical and subtropical regions of Asia, Africa, and Latin America (Li et al. 2003). The emergence of bamboo has provided several benefits to humans (Sharma et al. 2014). For example, bamboo is a suitable substitute for wood due to its advantages of a short rotation period, strong regeneration ability, good properties for wide use, and excellent performance; these properties are similar to or

even superior to those of wood (Yang et al. 2004). Therefore, a growing number of countries, and especially China, use bamboo as a common building material to save wood (Van der Lugt et al. 2006; Sharma et al. 2014). Bamboo also plays a crucial role in combating degradation of mountain environments, ecosystems, and natural resources (Yang et al. 2004). Furthermore, young, tender bamboo shoots are used as a seasonal vegetable in both rural and urban areas of China (Borah et al. 2008). However, unfortunately, bamboo is vulnerable to damage from herbivorous insect pests throughout its lifetime; thus, pests are the main cause of the massive loss of bamboo in natural and plantation forests (Liese and Köhl 2015).

China has abundant bamboo resources, with 753 species accounting for approximately 50% of the world's bamboo (Shi et al. 2020). Bamboo is widely distributed in China and is found in 27 of the 34 provincial administrative regions (Shu et al. 2015). In China, the output value of bamboo reaches 45 billion yuan per year, which has contributed significantly to China's economic development (Shu et al. 2015). However, in recent years, due to the emergence of numerous bamboo pests, bamboo production has declined sharply (Yang et al. 2011; Shu et al. 2015), causing serious economic losses. Therefore, strengthening the management and control of bamboo pests is conducive to the steady growth of China's economy.

Anaka burmensis Dworakowska, 1993 and *Cicadella viridis* (Linnaeus, 1758) are two important bamboo pests (Xu and Wang 2004; Yang et al. 2007; Dong et al. 2017). Both pests are tiny insects, with body sizes of 3.45–4.05 and 6.2–10.8 mm, respectively (Chen et al. 2012). Owing to this characteristic, they can only be observed when they congregate. Both pests have varying feeding behavior. *Anaka burmensis* feeds on the content of the cells, resulting in the formation of "white spots" or "hopper burn" on the leaf surface. *Cicadella viridis* is a xylem feeder and causes no considerable damage to the leaf surface. They prefer feeding on the stem or larger veins of the plant where they can easily reach the xylem tubes.

Anaka burmensis is distributed across southern China, including Guizhou and Yunnan (Dong et al. 2017), whereas *C. viridis* is more widely distributed in northern China (Liu et al. 2004; Lin et al. 2016; Zhao et al. 2022). Determining the distributional range of a pest is essential for its control; however, the distribution of these two pests has not yet been fully investigated. Traditional manual surveys cannot completely determine the distribution of pests in large geographical areas, such as China, due to limited resources and failure to predict the distributional range of species due to climate change. This frequently results in the use of pest control measures during outbreaks, causing large economic losses. Therefore, preventive methods are urgently required to solve this problem.

Species distribution models use occurrence records and environmental data to produce a model of the species' requirements and a map of its potential distribution (Anderson et al. 2002). Currently, species distribution models have been widely recognized as a useful tool for predicting pest distribution areas (Geng et al. 2011; Kumar et al. 2016; Huang et al. 2019; Xu et al. 2020). Among species distribution models, the Maxent model is the most commonly used, largely because it has significant advantages of requiring only a small sample size and having good performance compared with other models. Phillips et al.

(2006) compared the performance of Maxent and GARP (Genetic Algorithm for Ruleset Prediction) models based on 10 random subsets of the occurrence records for two Neotropical mammal species and found that the Maxent model was almost always higher, suggesting that it better predicted species distribution than the GARP model.

In this study, we used a Maxent model to predict the current and future potential distribution areas of *A. burmensis* and *C. viridis* in China using occurrence records and environmental data. We aim to answer two questions: 1) where are the potential distribution areas, both currently and in the future, and 2) how has the potential distribution area changed over time?

Materials and methods

Occurrence records

We collected the occurrence records of *Anaka burmensis* and *Cicadella viridis* in China from the literature and from the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/). Occurrence records that lacked latitude and longitude data were georeferenced using Google Earth. Sampling bias in geographic space frequently arises due to unequal sampling efforts, which can lead to incorrect predictions in species distribution models (Kramer-Schadt et al. 2013; Boria et al. 2014; Fourcade et al. 2014). Therefore, we conducted spatial thinning for the occurrence records with a 10-km distance using the R software package "spThin" to reduce the effect of sampling bias (Aiello-Lammens et al. 2015). After spatial thinning, 18 and 135 occurrence records of *A. burmensis* and *C. viridis* were obtained, respectively (Fig. 1, Suppl. material 1: table S1).

Environmental variables

We used 19 bioclimatic variables (1970–2000) and one elevation datum (altitude) from the current period as the current environment variables. To minimize multicollinearity among environmental variables, we calculated the variance inflation factor for the corresponding environmental variable values of the occurrence records of *A. burmensis and C. viridis*. Then, we eliminated the environment variable with the largest variance inflation factor each time until the variance inflation factor values of selected environment variables were less than 5. Finally, four environmental variables were retained for *A. burmensis*: mean diurnal range (bio2), mean temperature of wettest quarter (bio8), precipitation of warmest quarter (bio18), and precipitation of coldest quarter (bio19), whereas five environmental variables were retained for *C. viridis*: isothermality (bio3), mean temperature of wettest quarter (bio8), precipitation of driest month (bio14), precipitation seasonality (bio15), and precipitation of warmest quarter (bio18).

We selected future bioclimatic variables for the periods 2021–2040, 2041–2060, and 2061–2080 from the Coupled Model Intercomparison Project Phase 6 (CMIP 6). Four main emission scenarios driven by different socioeconomic assumptions are provided for CMIP6: SSP126, SSP245, SSP370, and SSP585. However, to avoid extreme simulation, the SSP245 scenario, a moderate emission scenario, was used (Hwang et al. 2022). In addition, due to the uncertainty

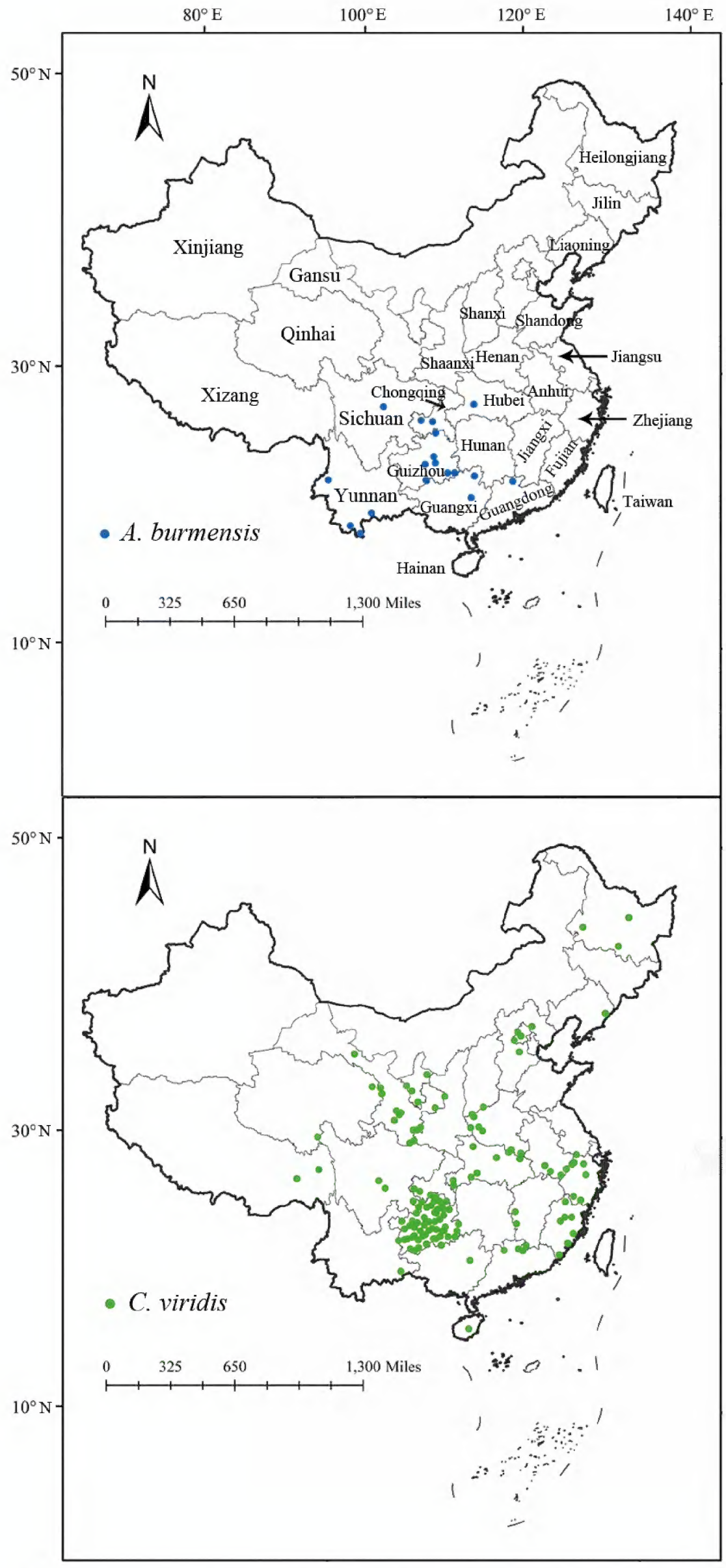

Figure 1. Occurrence of *Anaka burmensis* and *Cicadella viridis* in China.

of future climate models, future bioclimatic variables of the SSP245 scenario were obtained by calculating the mean from CanESM5, IPSL-CM6A-LR, and MI-ROC6 models (Zhao et al. 2024).

The bioclimatic variables and elevation data were obtained from the WorldClim database (http://www.worldclim.org), with a 2.5-arc min spatial resolution (~5 km resolution at the equator).

Maxent model

The model was developed in Maxent software v. 3.4.4. Regular multipliers (RM) and feature classes (FC) are closely related to the accuracy of the Maxent model (Phillips and Dudík 2008). Therefore, we used the ENMeval package in R software to choose the best combination of FC and RM values based on the lowest Akaike's Information Corrected Criterion (AICc) score (Muscarella et al. 2014). The RM values ranged from 1 to 4 in increments of 1, while eight FC were used: (i) Linear (L); (ii) Linear and Quadratic (LQ); (iii) Linear, Quadratic, and Hinge (LQH); (iv) Hinge, Product, and Threshold (HPT); (v) Quadratic, Hinge, and Product (QHP); (vi) Linear, Quadratic, Hinge, and Product (LQHP); (vii) Quadratic, Hinge, Product, and Threshold (QHPT); (viii) Linear, Quadratic, Hinge, Product, and Threshold (LQHPT). After the above process, an RM of 3 and the FC LQH were selected for *A. burmensis* and an RM of 1 and the FC LQ were selected for *C. viridis*. In addition, 10,000 background points, five repetitions with cross validation, and logistic output were set to run the model. The performance of the Maxent model was evaluated based on the area under the receiver operating characteristic curve (AUC) and true skill statistic (TSS). The AUC and TSS values greater than 0.75 and 0.6 respectively were considered useful (Elith 2002; Ben Rais Lasram et al. 2010). The importance of environmental variables was measured using the jackknife method. The 10^{th} percentile training presence logistic threshold was used to define the potential distribution areas (Bosso et al. 2016; Fan et al. 2020; Wei et al. 2020; Wei et al. 2021).

Shift in potential distribution areas

To quantify the distributional shifts between the current and future potential distribution areas, centroid analysis was performed using the SDMtoolbox 2.0 tool. This analysis converts the species distribution to a central point (centroid) and creates a vector to describe the direction and magnitude of the change through time (Brown 2014). We obtained the distribution shift by tracking the change of the centroid.

Results

Model validation and important variables

The results showed that the mean test AUC for *Anaka burmensis* and *Cicadella viridis* were 0.887 and 0.869, respectively (Fig. 2). Moreover, mean TSS values for *A. burmensis* and *C. viridis* were 0.691 and 0.614, respectively. The jackknife test revealed that the most important variable that affected the distribution of *A. burmensis* was precipitation in the coldest quarter (bio19), followed by precipitation in the warmest quarter (bio18) (Fig. 3). The mean temperature of the wettest quarter (bio8) was found to be slightly less important than the precipitation in the warmest quarter (bio18). The mean diurnal range (bio2) had

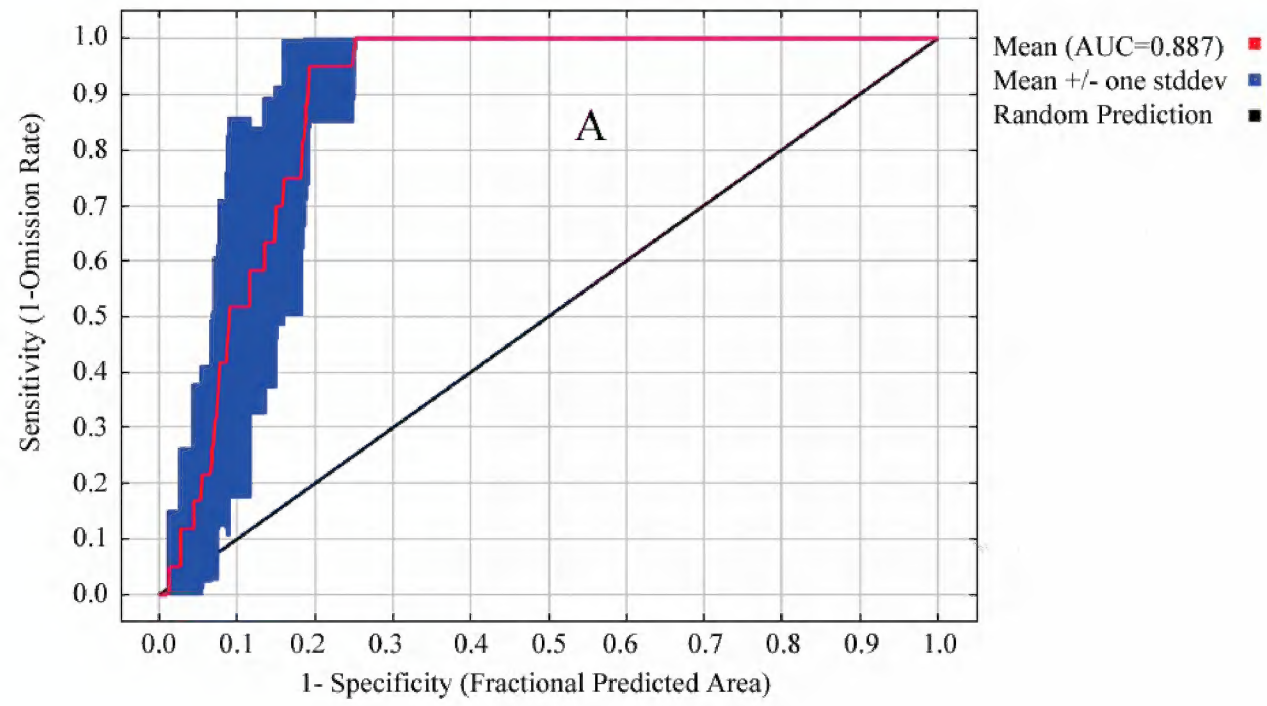

Figure 2. Receiver operating characteristic curve for *Anaka burmensis* (**A**) and *Cicadella viridis* (**B**).

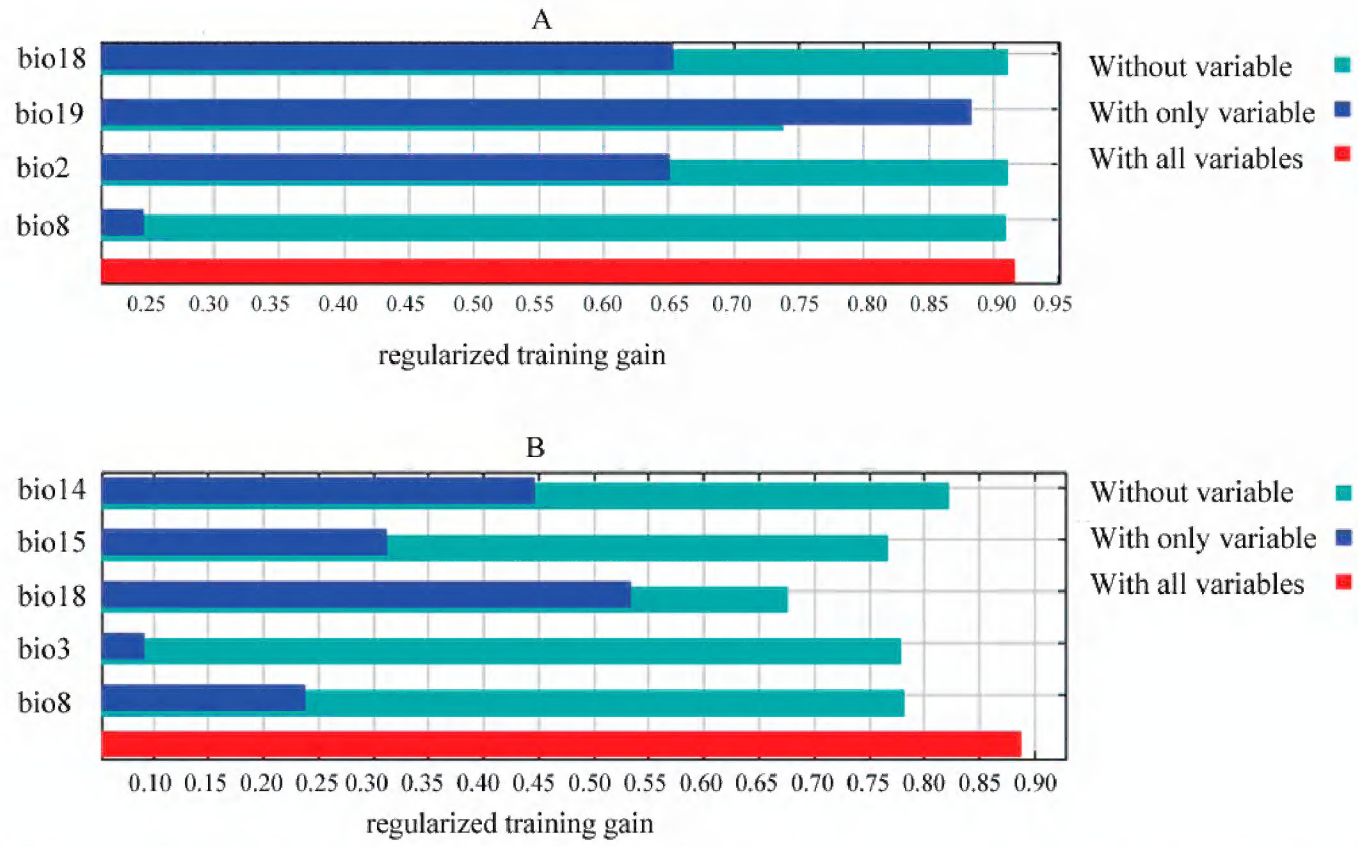

Figure 3. The importance of environmental variables for *Anaka burmensis* (**A**) and *Cicadella viridis* (**B**) based on the jackknife test.

the lowest contribution to the distribution of *A. burmensis*. The most important variable that affected the distribution of *C. viridis* was found to be precipitation in the warmest quarter (bio18), followed by precipitation in the driest month (bio14) (Fig. 3). The mean temperature of the wettest quarter (bio8) and precipitation seasonality (bio15) were found to have moderate impacts. The variable with the lowest impact was isothermality (bio3) (Fig. 3).

Potential distribution areas and changes

The current and future potential distribution area for two pests in China was obtained by Maxent model (Figs 4, 5). The current potential distribution area for *A. burmensis* was predicted to be 2.29×10^6 km^2 (Table 1) and was mainly concentrated in provincial administrative divisions of southern and central China (Fig. 4), including Guizhou, Chongqing, Guangxi, Hunan, Hubei, Guangdong, Jiangxi, Fujian, Anhui, Zhejiang, and Jiangsu. Potential distribution areas have also emerged in Xizang, Sichuan, Yunnan, Hainan, and Taiwan (Fig. 4).

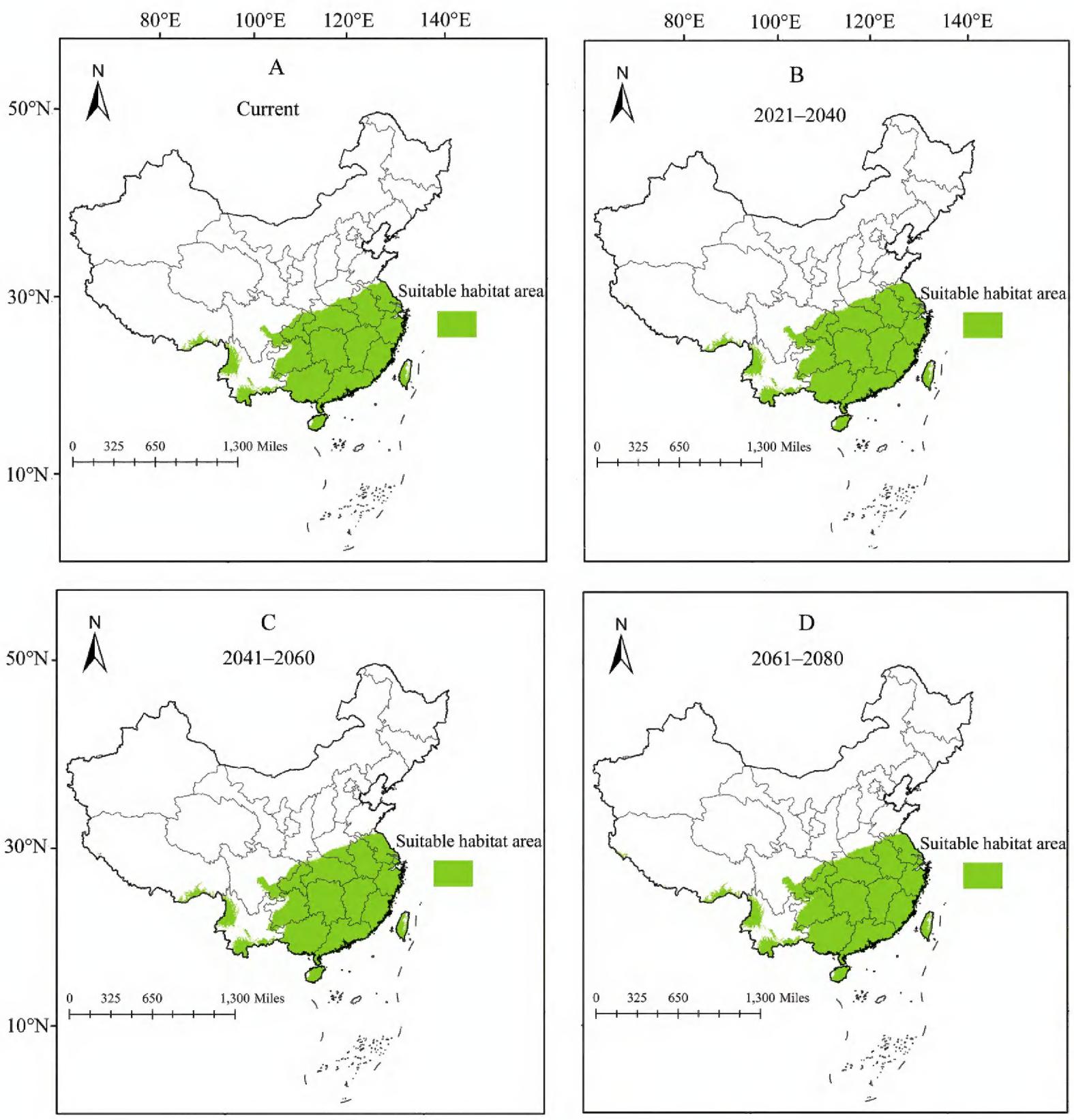

Figure 4. Potential distribution areas of *Anaka burmensis* in China during different periods.

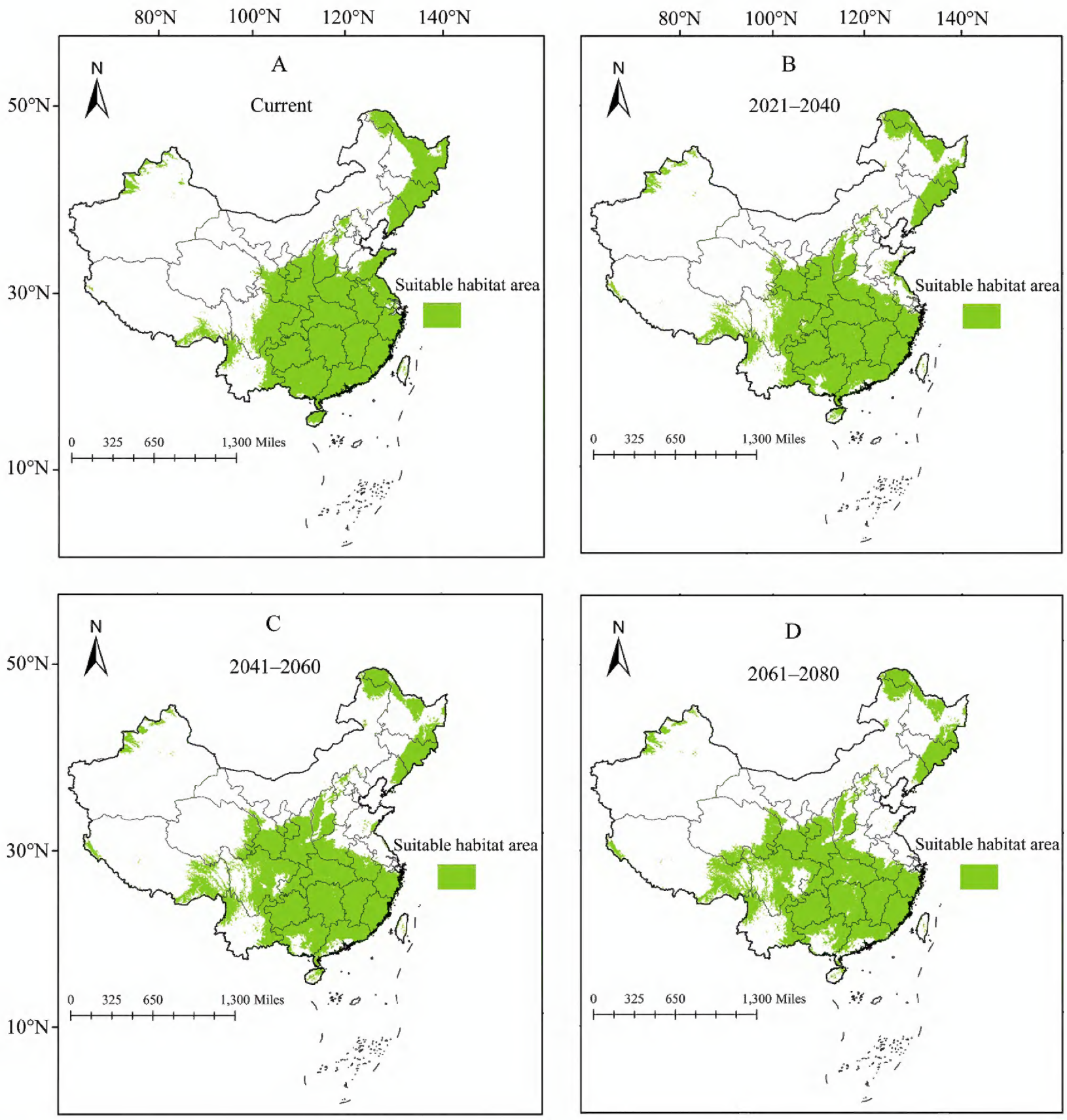

Figure 5. Potential distribution areas of *Cicadella viridis* in China during different periods.

Table 1. Predicted distribution areas (km^2) for *Anaka burmensis* and *Cicadella viridis* during different periods in China.

	Current	2021–2040	2041–2060	2061–2080
A. burmensis	2.29×10^6	2.35×10^6 (+2.62%)	2.37×10^6 (+3.49%)	2.42×10^6 (+5.67%)
C. viridis	4.42×10^6	4.16×10^6 (−5.88%)	4.08×10^6 (−7.69%)	4.05×10^6 (−8.37%)

Three future periods showed increases in the size of predicted distribution area for *A. burmensis*, with increases of 2.62%, 3.49%, and 5.67% in 2021–2040, 2041–2060, and 2061–2080, respectively (Table 1). Centroid analysis revealed that centroids representing potential distribution areas moved 7.7 km north in 2021–2040, 8.8 km northwest in 2041–2060, and 17.7 km west in 2061–2080 (Fig. 6). This result revealed a slight shift in potential distribution areas.

The current potential distribution areas for *C. viridis* in China are projected to be 4.42×10^6 km^2 (Table 1), an area which is larger than that projected for *A. burmensis*. Numerous provincial administrative divisions in central, southern,

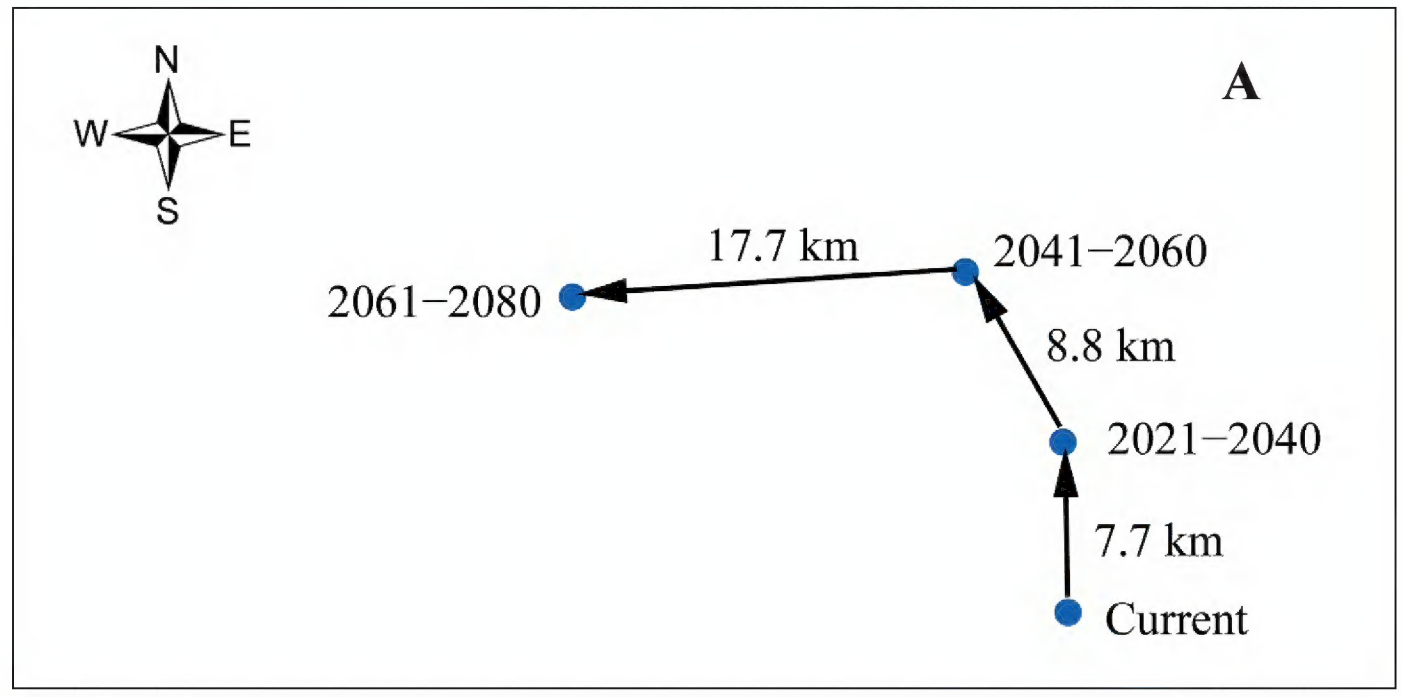

Figure 6. Shift in potential distribution areas of *Anaka burmensis* (**A**) and *Cicadella viridis* (**B**) in China.

and northeastern China have become major potential distribution areas for *C. viridis*, such as Guizhou, Hunan, Hubei, and Heilongjiang (Fig. 5). The future potential distribution areas were found to be decreased compared with the current areas by 5.88% in 2021–2040, 7.69% in 2041–2060, and 8.37% in 2061–2080 (Table 1). Overall, potential distribution areas for *C. viridis* are predicted to move toward the southwest in 2021–2040 (135.7 km) and 2041–2060 (77.4 km) and toward the northwest in 2061–2080 (72.8 km) due to climate change (Fig. 6).

Discussion

In the present study, the Maxent model was used to predict the current and future potential distribution areas of two pests that seriously harm bamboo in China. In addition, the spatial variation of potential distribution areas over time was investigated. The mean AUC and TSS value of five runs of the Maxent model for the two pests was high, suggesting that the constructed models have good performance and usefulness.

This study revealed that precipitation is the most important environmental factor driving the distribution of *Anaka burmensis* and *Cicadella viridis*. This is consistent with the findings of previous studies on other pests, such as *Moritziella castaneivora* Miyazaki, 1968 (Wang et al. 2010), *Riptortus pedestris* (Fabricius, 1775) (Zhang et al. 2022), and *Spodoptera frugiperda* (Smith, 1797) (Ramasamy et al. 2022). Therefore, the results of the current and previous studies

suggest that precipitation is a key factor for pest distribution. Furthermore, the current potential distribution areas of *A. burmensis* and *C. viridis*, as predicted by the Maxent model, were not only present in these provinces with occurrence records but also in several other provinces. This result largely reflects serious insufficiency in the current field investigation for the two pests and suggests that the Maxent model can be used as a pest monitoring tool.

The main distribution range of the current and future potential distribution areas of *A. burmensis* and *C. viridis* is the main distribution area of bamboo in China (Xu et al. 2019), which implies that bamboo in China is potentially threatened by these two pests. The potential distribution areas and the spatial change of *A. burmensis* and *C. viridis* identified in this study are extremely important in providing guidance for the management of these pests. For instance, management efforts for *A. burmensis* should continue to be focused on the southern and central China due to insignificant changes in the future. Moreover, the potential distribution areas for *C. viridis* appear to have a slight reduction in the future compared with current, but anticipated expansion of potential distribution areas in Sichuan, Qinhai, and Xizang is predicted; therefore, it is vital to develop effective preemptive strategies (e.g. strict quarantine measures) to prevent the introduction of this pest into these regions.

Zhang et al. (2023) used a Maxent model to predict current and future potential distribution areas of *C. viridis* globally. In their study, many areas in China were found to be environmentally suitable for this pest, but there was a huge difference from our prediction; the distribution of potential distribution areas found in our study revealed a greater range, with northeast Liaoning and northeast Heilongjiang becoming potential distribution. Wei et al. (2023) also obtained potential distribution areas of *C. viridis* in China using the Maxent model and found that most areas have become environmentally suitable. Although the abovementioned two studies have identified potential distribution areas in China, there are common or unique limitations in the modelling process, such as the use of untuned key parameters (i.e., FC and RM) for two studies and outdated future climate data in the study of Wei et al. (2023). Consequently, prediction results of the two studies are highly likely to be biased. Objectively, our results are more accurate due to the use of a more correct modeling process.

Although this study forecasted potential distribution areas for the two pests, the results must be interpreted with caution and some limitations should be acknowledged. All data for the modelling process were derived from GBIF and the literature. It is important to supplement these data with field investigation in future studies and perform the test of prediction. For example, by going to the field where the distribution of the species is predicted, we can confirm that the species is found in the field. Moreover, species distribution is determined by three factors: (1) the capacity to reach a suitable location; (2) the capacity to develop in a certain environmental condition; and (3) the ability to compete with other species occupying the same region (Begon et al. 2005). However, in our study, we only considered the effect of climate on species distribution. Furthermore, the physiological needs of species are plastic and may change over the course of evolution (Thomson et al. 2010), a fact that should be considered in future research.

Conclusions

In summary, the current and future potential distribution areas of *Anaka burmensis* and *Cicadella viridis* in China were obtained using the Maxent model. The results of this study demonstrated that precipitation is the most important environmental factor in shaping the distribution of these two pests. In addition, the findings of this study will assist policymakers and governments in developing appropriate measures for managing and controlling *A. burmensis* and *C. viridis*, thereby decreasing the damage to bamboo and the associated significant economic loss.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Funding

This study was supported by the National Natural Science Foundation of China (no. 31860209) and the Science and Technology Support Program of Guizhou Province (no. 20201Y129).

Author contributions

Zhengxue Zhao: distribute data collection, data analysis, and manuscript writing. Lin Yang and Xiangsheng Chen: manuscript revising.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Supplemenatry data

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Data type: xlsx

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Link: https://doi.org/10.3897/zookeys.1203.118978.suppl1